Chapter

Traffic Flow Analysis and Management

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Abstract

This research is about joint government founded program between Japan and India or Science and Technology Research Partnership for Sustainable development (SATREPS). The purpose of this research is to establish Low Carbon Transportation in developing countries and we choose one of major city in India, where it is Ahmedabad city of Gujarat state—west cost of India. In order to approach the target, we need to understand the current situation of traffic condition in the city. The current traffic condition in India is some chaotic because of their different driving behavior compared with the advanced countries. It is becoming the chaotic traffic condition in India by not only diving behavior during investigation of this research. The main reason of the traffic congestion comes from the unbalance between growing transportation demand and its insufficient infrastructure preparation. In this chapter, it introduces the current traffic condition based on four years monitoring of the traffic by the traffic monitoring cameras and comparison by the traffic flow theory at first. Then it introduces the new traffic analysis method especially for its traffic congestion analysis and its parameters. After the traffic congestion analysis, it summarizes conclusion and our next step from the experience.

Keywords: traffic flow, intelligent transport system, traffic density, traffic volume, developing country transportation

1. Introduction

Transportation is important for human been activity as the economy grows. Under rapid growing economy, it always happens negative impact by growing transportation because of i-balance between transportation demand versus infrastructure development such as road construction, traffic control management system, public transportation implementation, and so on. Negative impact occurs as the following—traffic congestion, traffic accident, un-necessity fuel consumption, environment destruction, air prolusion, noise pollution, traffic fatality—as transportation issues in general. There is no exception bout this transportation issue in the world, not only developing countries but also advanced countries. Therefore it is important to understand traffic flow condition and mechanism of traffic congestion reason at least.

In order to understand traffic flow, it is necessary to measure the traffic condition by traffic monitoring system such as traffic video monitoring camera, other sensing technology for directly collection vehicle movement like smart phone, navigation system in vehicles, drone camera, 3D sensor camera, infrared camera, Bluetooth device in vehicle, and many other high-technology tool available. But the point is how to collect accurate traffic data as real traffic flow and under developing counters, it becomes challenge to understand the real traffic condition from the data rather than in advanced counties. In this book, it is introduced traffic flow analysis method combined with traffic flow theory.

After collecting traffic data and analysis, it digs into traffic flow problem and shows important traffic flow parameter for traffic congestion with using actual traffic measurement data in a major city in India. And it shows city level traffic flow visual analysis by Geographic Information System (GIS) tool to understand its traffic issues and some countermeasures.

Based on this project, it mentioned what we learn and how to approach for solving the issues. Technology becomes higher and provides us better solution. In conclusion, author wants to share the idea that technology is one of tool for helping collecting data and we need to know how to creating our experience and how to use it as sustainable concept. At last part, author adds traffic fatality issues from fifty years Japanese experience with some enhanced experimental equation in appendix.

2. Case study of project

2.1 Case study field

This project has been started since April 2017 under SATREPS program, which is government founded joint research project between Japan and India. The case study filed was chosen in the Ahmedabad city of Gujarat state India, which is one of typical rapid economic growing and faced to serious traffic issues. The population of Ahmedabad city is over 8 million [1] in 2018 from 5 million in 2011 and the number of vehicles is about 4 million in 2017 [2]. More than 70% vehicle is two wheelers, which is typical percentage in developing countries. Based on city government or Ahmedabad Municipal Corporation (AMC) agreement, the case study field was chosen in west side of the city called “New City” where there will have more commercial business and new building constructions (**Figure 1** and **Table 1**).

2.2 Monitoring traffic in Ahmedabad

First, it is necessary to have monitoring tools for measuring traffic condition in the city. In this program, we installed traffic video monitoring cameras shown in **Figure 2**. This is general camera in traffic industry. And the special high resolution 4 K camera is installed at the major junction—Pladi junction as detail analysis at junction.

Second, the total number of cameras is 36 including 4 K camera. The camera location is shown in **Figure 3** (The number is camera ID and 4 K camera has no number, but it is in the center among 2000s ID cameras in the map). The traffic video camera has several functions such as counting number of vehicles on the road, average vehicle speed, traffic density, occupancy and so on. Traffic density is the number of vehicles per kilo meter on the road (vehicle/km) which is defined in the traffic flow theory. Occupancy is how much percentage occupied by vehicles on the road which is also defined in the traffic flow theory. The detail parameter explanation is described in later of this chapter.

Third, here is an example of traffic condition data which is shown in **Figure 4**. There are two graphs shown which are time-based traffic volume and average vehicle speed. From those graphs. we see the traffic condition (in this case camera #2 location). It is clear that the traffic congestion was occurred around 20:00 o’clock because its traffic volume was peek and average vehicle speed is lowest. The data here is a month data in June 2019 and each graph shows average point and standard deviation.

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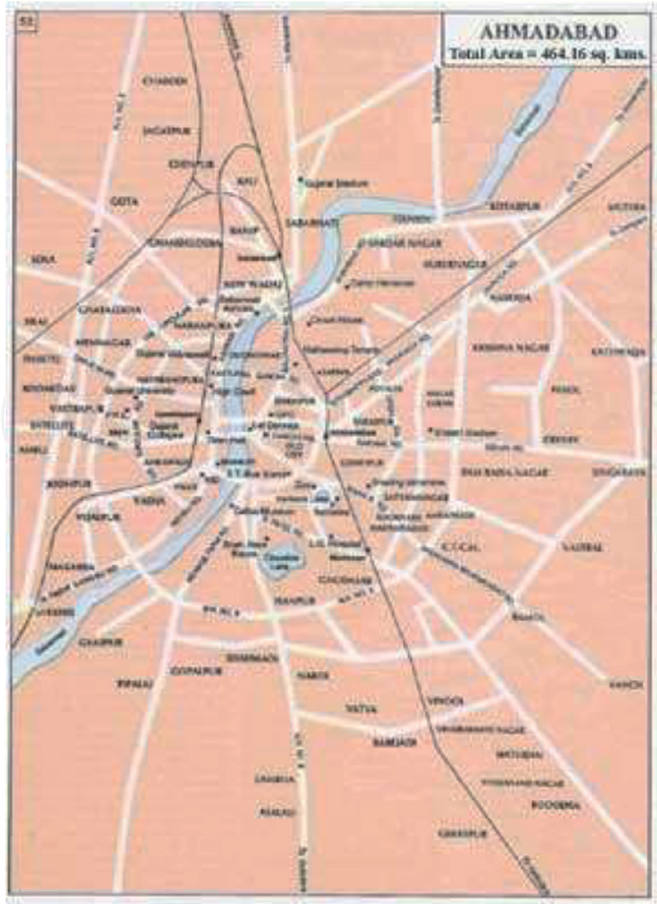

Figure 1.
Ahmedabad city map [3].

Co-ordinates:	23.03° N 72.58° E
Area:	466 Sq.km. (year 2006)
Population:	55,77,940 (year 2011 Census)
Density:	11,948 /sq.km
Literacy Rate:	89.60%
Average Annual Rainfall:	782 mm
Popularly known as:	Amdavad
STD Code:	079

Table 1.
Profile: Ahmedabad City [3].

2.3 Traffic flow theory and measurement

2.3.1 Traffic flow theory

In this section, it is necessary to understand the basic Traffic Flow Theory then compare between the theory and measurement result of traffic flow. The traffic flow analysis originally comes from fluid mechanism theory. When average vehicle speed (v) (km/h)on a road and the density of vehicle which is so called Traffic Density (k)(veh/km), the Traffic Volume (q) (veh/h) is obtained by Eq. (1).

$$q = k \times v \tag{1}$$

Figure 2.
Traffic video monitoring camera and high resolution 4 K camera (photo by zero sum ltd).

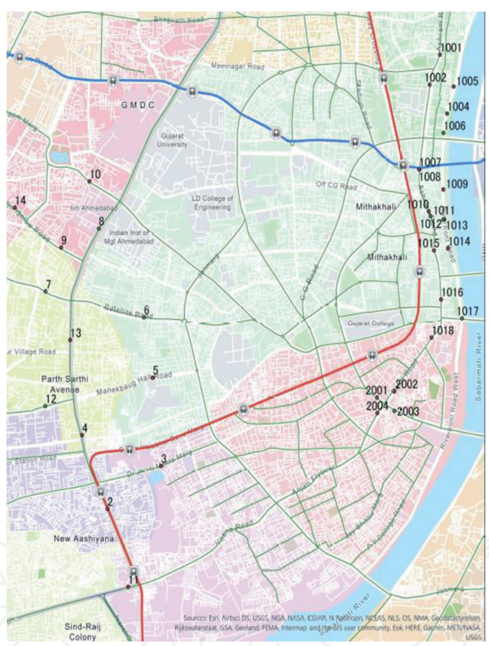

Figure 3.
Traffic video monitoring camera location.

And the fundamental relationship between (k) and (v) is defined as Greenshields [4] in Eq. (2).

$$v = v_f \left(1 - \frac{k}{k_j} \right) \quad (2)$$

where v_f is free speed which is theoretical maximum speed at zero traffic density and k_j is jam traffic density which is theoretical zero vehicle speed condition. From Eq. (1) and Eq. (2), Eq. (3) is obtained.

$$q = v_f \left(1 - \frac{k}{k_j} \right) k \quad (3)$$

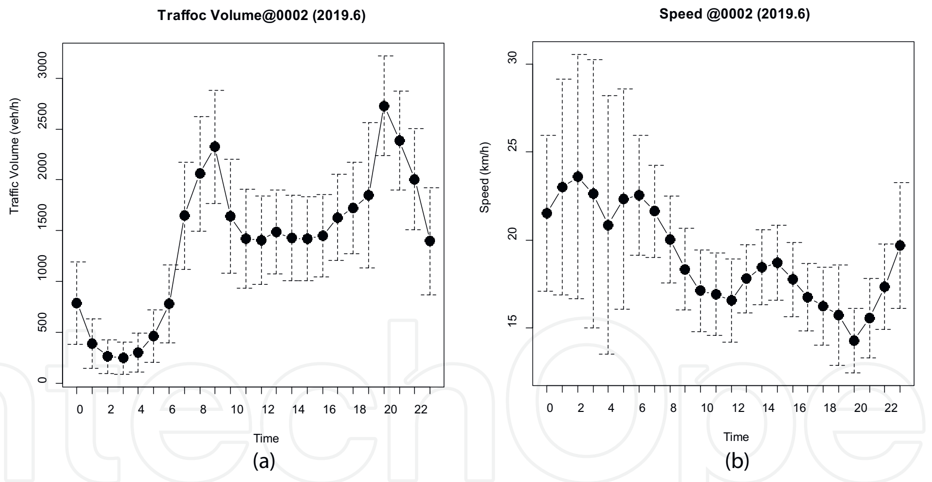

Figure 4.
Example of traffic condition at camera#2. (a) Time-based traffic volume (b) Timeobased vehicle speed.

Eq. (4) is obtained by changing Eq. (3) as traffic density quadratic equation.

$$q = -\frac{v_f}{k_j}\left(k - \frac{k_j}{2}\right)^2 + \frac{v_f k_j}{4} \tag{4}$$

By using Eq. (2) and Eq. (4), we have two funder mental traffic characteristics in **Figure 5**.

From K-Q curve in **Figure 5**, traffic congestion occurs between k_c to k_j because traffic volume Q is decreasing at q_c.

2.3.2 Traffic flow measurement

From measurement data, the fundamental traffic flow characteristics are shown in **Figure 6** as an example of Camera#2 in June 2019.

By comparing **Figures 5** and **6**, the boundary line of each characteristics is similar shape. But the measured data spreads under the boundary line. It is

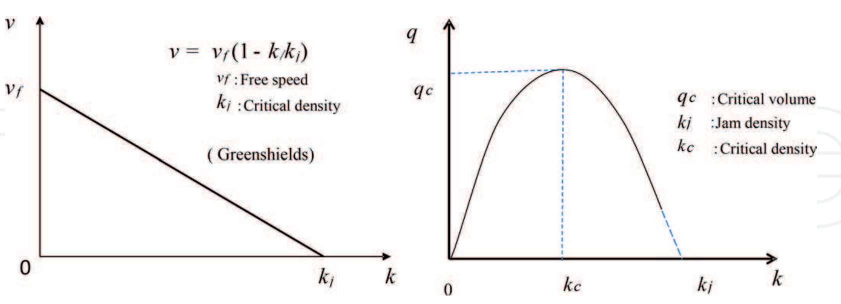

Figure 5.
Fundamental traffic flow characteristics.

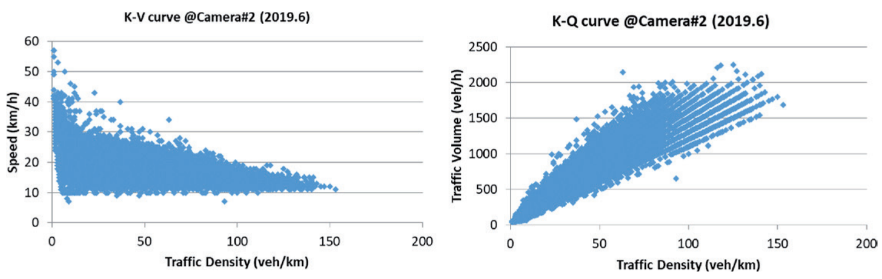

Figure 6.
Fundamental traffic flow characteristics at camera#2.

difficult to figure out the traffic congestion condition from measurement data. We see the traffic congestion occurs around 20:00 at Camera#2 from **Figure 4**. Therefore, the measurement funder mental traffic flow is shown by time zone base in **Figure 7**. There are six time zone from 7:00–10:59 as T1, 11:00–14:59 as T2, 15:00–18:59 at T3, 19:00–22:59 as T4, 23:00–2:59 as T5, and 3:00–6:59 as T6. Then T4 is most critical traffic congestion condition. From **Figure 7**, we see the traffic congestion at Camera#2 in June 2019 occurs the area of the funder mental traffic flow characteristics under its boundary line. This is one of typical features of traffic flow characteristics in India. The traffic congestion occurs before its critical traffic volume (q_c) (refer to **Figure 5** K-Q curve). This research has been done in previous study for time-zone based visualization of traffic flow [5].

When we use the boundary line as its traffic flow characteristics, we get the traffic flow parameter. The example of boundary line for **Figure 6** is shown in **Figure 8**. The we have the following parameter v_f = 38, k_j = 250 in this case. This is called in previous research as Boundary Observation Method [6].

2.3.3 Traffic congestion

In previous Section 2.3.2, we have traffic flow fundamental characteristics curve and traffic flow parameter i.e. free speed, jam traffic density. In terms of traffic congestion analysis, we only have an observation method by using Time-based Traffic Volume and Vehicle speed shown in **Figure 4**. In this section, we try to get one of some traffic parameters as its traffic congestion condition. In previous research [7], we focus on occupancy (OC) parameter. The occupancy is obtained by Eq. (5) from traffic theory.

$$OC = 100 \times \frac{q}{v} \times \bar{l}\ (\%) \tag{5}$$

where (q) is traffic volume, (v) is vehicle speed, and $\bar{l}$ is average length of vehicle.

Here is an example from our measurement data in **Figure 9**.

Figure 9 shows traffic condition of total traffic monitoring cameras in **Figure 3**. From **Figure 9**, occupancy shows traffic congestion condition well. In case of occupancy as traffic congestion parameter, we are able to see the traffic congestion condition. It is not necessary to use two parameter i.e. traffic volume (q) and average vehicle speed (v) like in **Figure 4**.

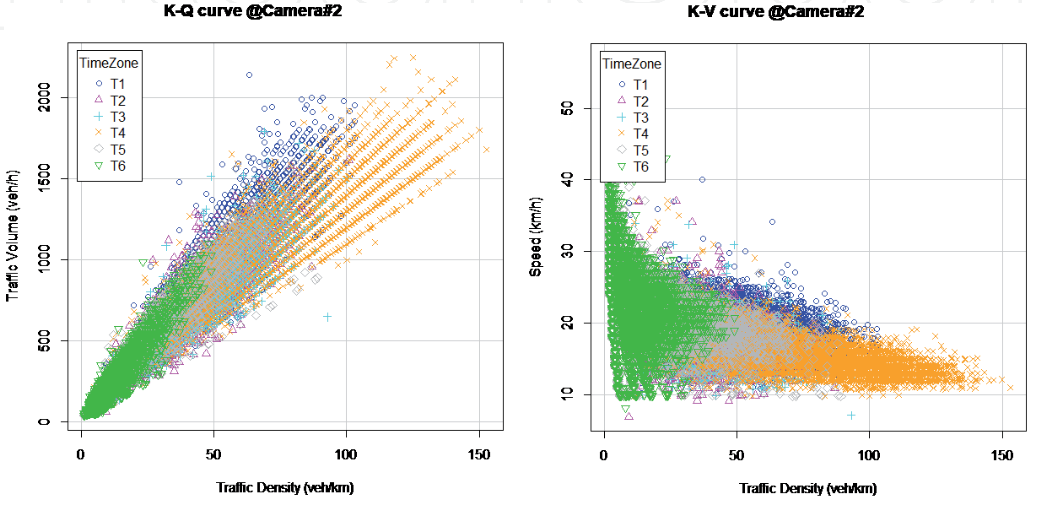

Figure 7.
Time zone based fundamental traffic flow characteristics.

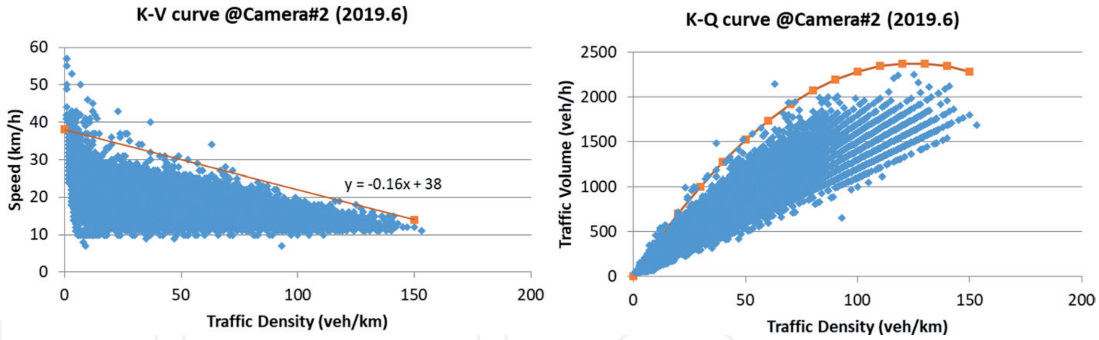

Figure 8.
Traffic flow characteristics with boundary line at camera#2.

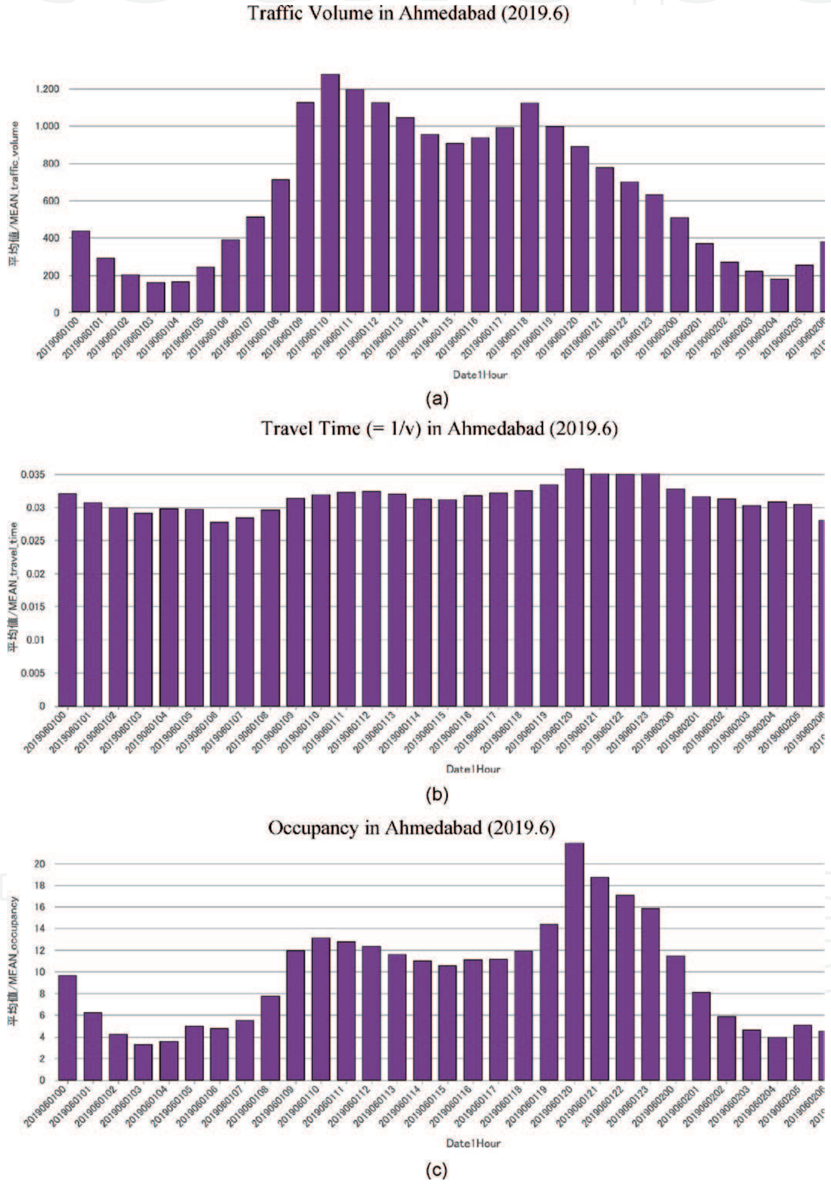

Figure 9.
Traffic flow parameter in Ahmedabad June 1st 2019. (a) Traffic Volume (q) in Ahmedabad June 1st 2019. (b) Travel Time (= 1/v) in Ahmedabad June 1st 2019. (c) Occupancy (OC) in Ahmedabad June 1st 2019.

2.3.4 Traffic congestion condition

The occupancy is useful to understand the traffic congestion condition from the traffic flow parameters in 2.3.2. By using the occupancy parameter in whole city, **Figure 10** shows the trend of traffic congestion condition in Ahmedabad.

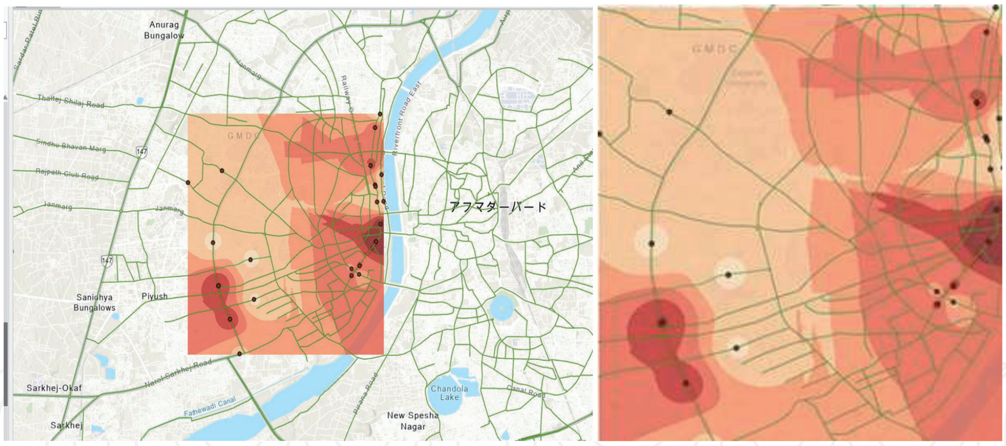

Figure 10.
Traffic congestion by occupancy in Ahmedabad June 1st 2019.

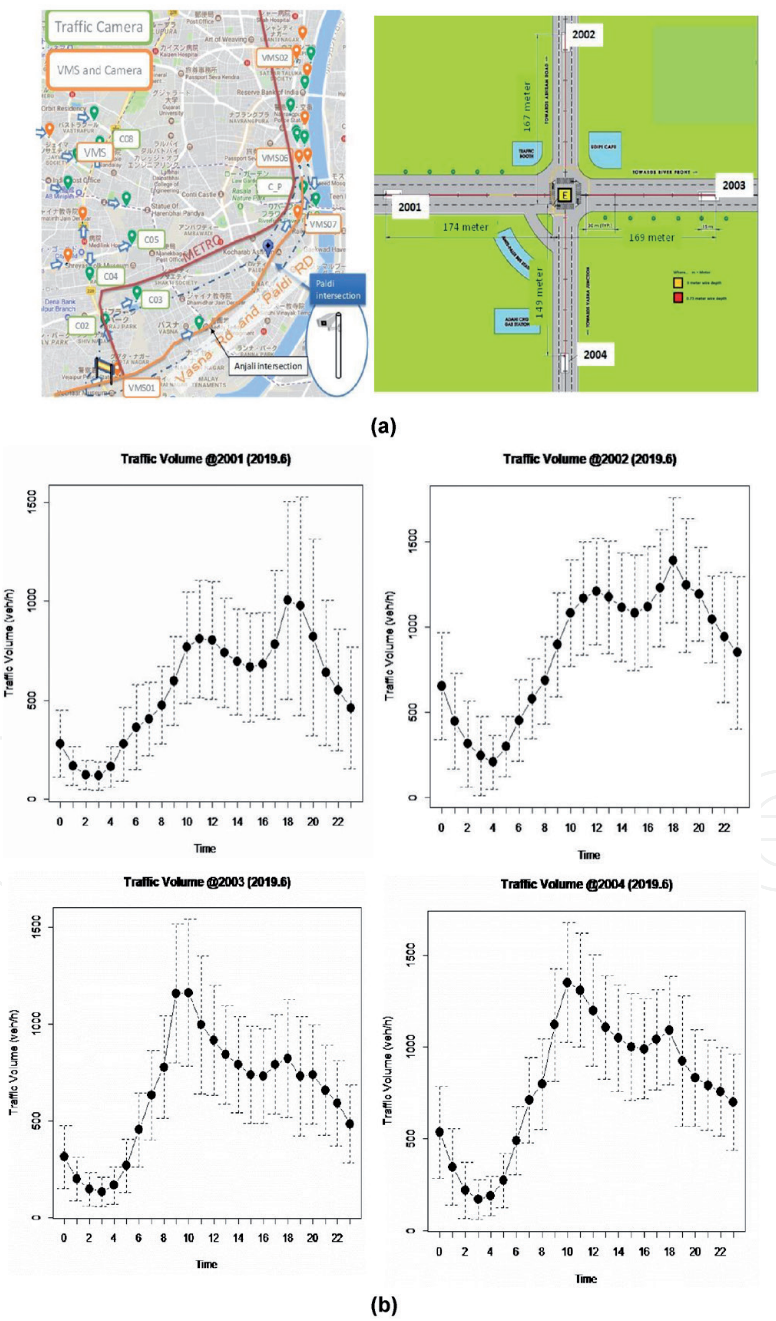

Figure 11.
Padli junction location relation map and traffic volume at Paldi. (a) Location Map (by Google MAP) and Paldi junction Camera position. (b) Traffic Volume at Paldi Junction (Camera#2001 to 2004).

Figure 12.
Drone traffic monitoring at Padli junction.

The data is used all traffic monitoring cameras and interpolation of Inverse Distance Weighted (IDW) with Geographical Information System (GIS) such as ArcGIS.

From **Figure 10**, it is clear about traffic congestion condition in Ahmedabad by using occupancy parameter. The left bottom area if **Figure 10** is crowed area because of shopping center and new business office along the road (132 Feet Ring Road) and the right side of middle area along the road (Ashram Road), which connects with the right side of city which is called "old city", where there are government office Ahmedabad Municipal Corporation (AMC), court, bus garage etc.

In Paldi junction sounded by Camera#2001 through Camera#2004, it is expected to become traffic congestion because the fly-over is under development Ashram Road from Camera#1 to Paldi junction (refer to **Figure 11**). There is METRO under development which will run Ashram Road in parallel (red line in **Figure 11(a)**). In **Figure 11(b)**, there are four graphs about traffic volume at Paldi Junction from Camera#2001 through 2004. From these graphs, there is interesting trend of Paldi Junction traffic. For Camera#2001 and 2002, there is more traffic in the evening rather that in the morning. On the other hand, for Camera#2003 and 2004, its trend is opposite. The direction of each cameras face to the center of Junction, this means many traffic moves from old city or east side of city to new city or west side of city. From these measurements of traffic condition in Ahmedabad, the value of occupancy is lower than 25% in wide area in the city. According to our experience of the project, there is not always congested against our expectation before this project stars. The Ahmedabad traffic congestion occurs by some reason, not always crowed by traffic. This is important evidence and hints how to solve traffic congestion issues in India.

Here is undergoing research activities for monitoring traffic condition. We use Drone at Paldi junction. **Figure 12** shows the video capture at Paldi junction in order to understand vehicle movement behavior. The Drone flied about 10-meter-high at Paldo junction. From the Drone video monitoring, it becomes clear vehicle behavior rather than that by traffic video monitoring camera because traffic video monitoring camera is installed at the fixed point and not high position in the sky. The detail analysis is done in our future work.

3. Traffic safety management

In previous section, we have traffic flow analysis at Paldi junction. From **Figure 12**, we see clear real vehicle behavior by Drone and each four direction of vehicle movement is controlled by traffic signal. In terms of traffic signal in India, the fixed cycle control method is used, which is typical signal control method in all India. There are several traffic signal control such as actuated control type and spatial control type. The actuated control type is to change traffic signal timing based on its waiting length of each direction of road. And spatial control time is to change traffic signal timing synchronized with multiple traffic signals nearby. In case of small number of vehicles, the fixed cycle control type is able to manage. But in accordance with number of vehicle growth, the waiting signal time becomes longer and it makes more que length of each roads. It is necessary to consider their traffic signal control sometime near future.

However there is more fundamental issues in Indian traffic signal. It is relatively quite small installation in major cities. **Figure 13** shows the number of traffic signal installation in major cities in the world [8].

From **Figure 13**, the number of traffic signal installation is quite small compared with other advanced countries, Japan, USA, UK, Singapore etc. In previous research about quantitative traffic safety analysis by Tsuboi.T [9], it is introduced "enhanced Smeed's Law", which is exposition of Smeed's Law. The Smeed's Law is able to explain the relationship between traffic fatality number, population, and number of vehciles [10]. The Smeed's Law equation is provide by Eq. (6) and the enhance Smeed's Law equation is provide by Eq. (7).

$$D = 3 \times 10^{-4} \left(np^2\right)^{\frac{1}{3}} \tag{6}$$

where D is the number of fatalities, n is the number of vehicle registrations, and p is the population.

$$D_{t+1} = D_t \left(1 + \frac{1}{3} N_t + \frac{2}{3} p_t\right) e^{-\gamma s_t} \tag{7}$$

where D_t, Nt, Pt, and St are the number of fatality, vehicles, population, and signal installation at time t. γ is an exponential constant of installation of signal.

By Smeed's Law and enhanced Smeed's Law, we have comparison results of Indian fatality in **Figure 14**.

Based on Japanese fatality record, **Figure 15** shows each Smeed's Law result and enhanced Smeed's Law result.

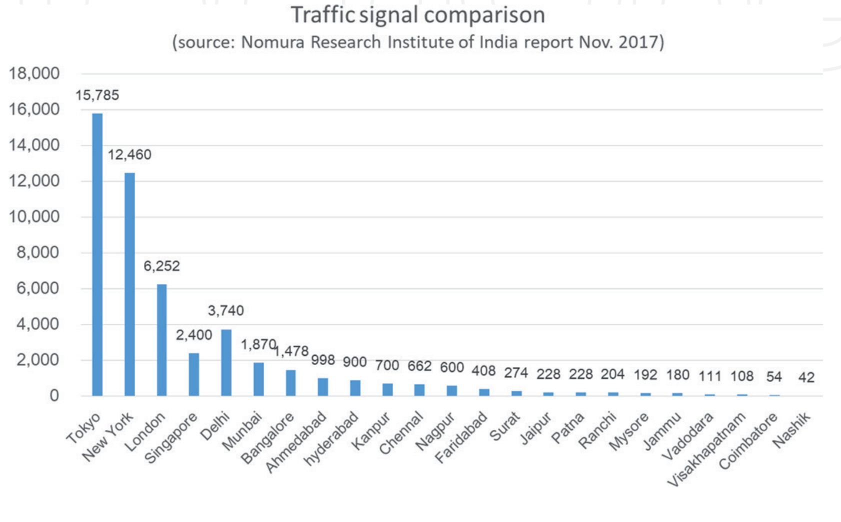

Figure 13.
Traffic signal installation comparison.

When we use γ parameter based on Japanese experience by Japanese traffic safety policy, it is able to expand to Indian fatality analysis in future. **Figure 16** shows the expectation analysis results of Indian fatality under Japanese traffic safety policy.

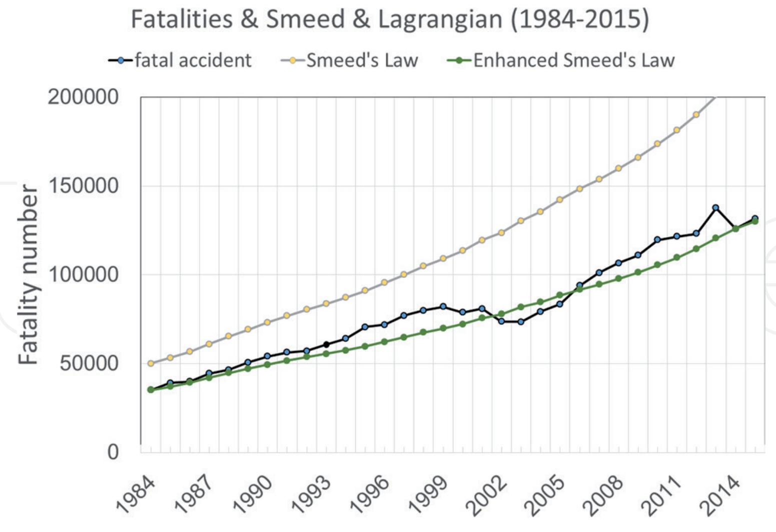

Figure 14.
Indian fatality analysis by Smeed's law and enhanced Smeed's law.

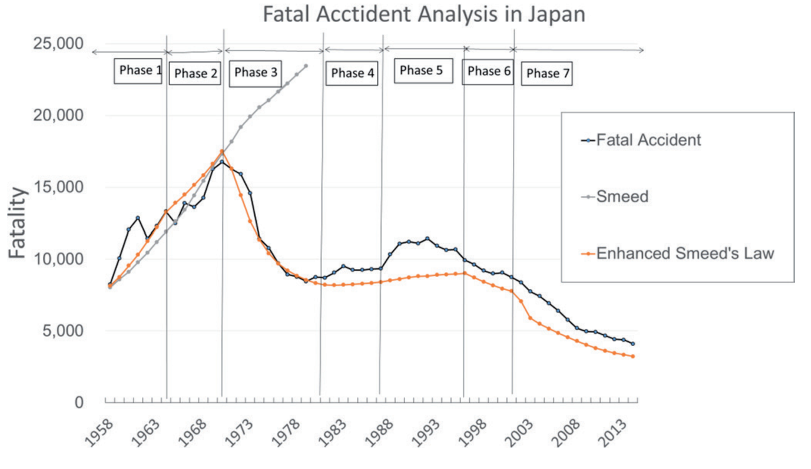

Figure 15.
Japanese fatality analysis by Smeed's law and enhanced Smeed's law.

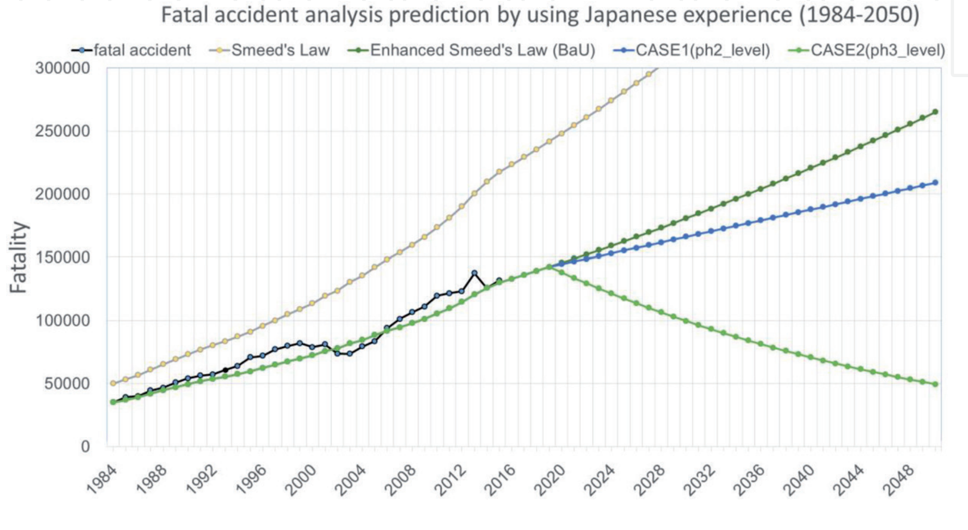

Figure 16.
Indian fatality analysis with Japanese traffic safety policy.

Year	Level	Major action & item	Note
Before 1964	Level 1	Under development for traffic management	
1964	Level 2	1st policy plan	
		Signal implementation	
1970	Level 3	2nd policy plan	
		Vehicle sensing installation	
		Sensitive type traffic signal	
1980	Level 4	3rd policy plan	
		Central control system for signal	Overall Japan
		Control center for signal control	ditto
		Traffic regulation & more installation	ditto
		Education for traffic	ditto
1987	Level 5	4th policy plan	
		Traffic signal algorithm improved	
		Traffic information display	
		Network among centers	
1996	Level 6	5th policy plan	
		ITS system development	
		Congestion control system (VICS)	
		Optimized algorithm (MODERATO)	

Table 2.
Traffic safety policy in Japan.

In **Figure 16**, there are several case studies—Business as Usual (BaU) which means there is nothing special to do with traffic safety, CASE 1 which follows Japanese traffic safety phase 2 level, and CASE 3 which follows Japanese traffic safety phase 3 level. Each level of Japanese safety policy is shown in **Table 2**.

From this case study, we understand that expansion of traffic signal installation is necessary but it is not enough to reduce the number of fatality in India.

4. Summary and discussion

In this chapter, we started how to measure and collect Indian traffic data and visualize its condition with somehow in quantitative value. And we use ordinal traffic video monitoring camera which has been used in worldwide in general. At the same time, we are able to use high technology tool such as drone in this book. But there are other several technologies available day by day like Artificial Intelligent (AI) and Deep Leering so on. But here is important things for traffic flow analysis is that transportation is a kind of human activities. Therefore, we cannot ignore the real people life during this research activities, we have many chance to talk and exchange information with local government and stakeholders of public transportation organization. One of interesting reason of Ahmedabad traffic congestion seems to be occurred in the evening because of people evening activities after their work, it is shopping, dinner with friends, not straight to go home. In current road infrastructure in India, there is no well-developed for transportation infrastructure, one of officer mentioned about public parking space problem. The lack of vehicle parking space in their roads, so when people goes to restaurant in the evening, there is no appropriate parking space, they park their vehicle along the street. Then its road becomes narrow by vehicle parking.

From this story, the traffic congestion is not always by just more vehicles. There is other fundamental reason such as lack of proper parking space in the city. This is unbalance between economic growth and infrastructure preparation. In **Figure 17**, we have four years ago traffic data in Ahmedabad. The condition of each area is not so much changed but just number of vehicles is 1.3 time in **Figure 18**.

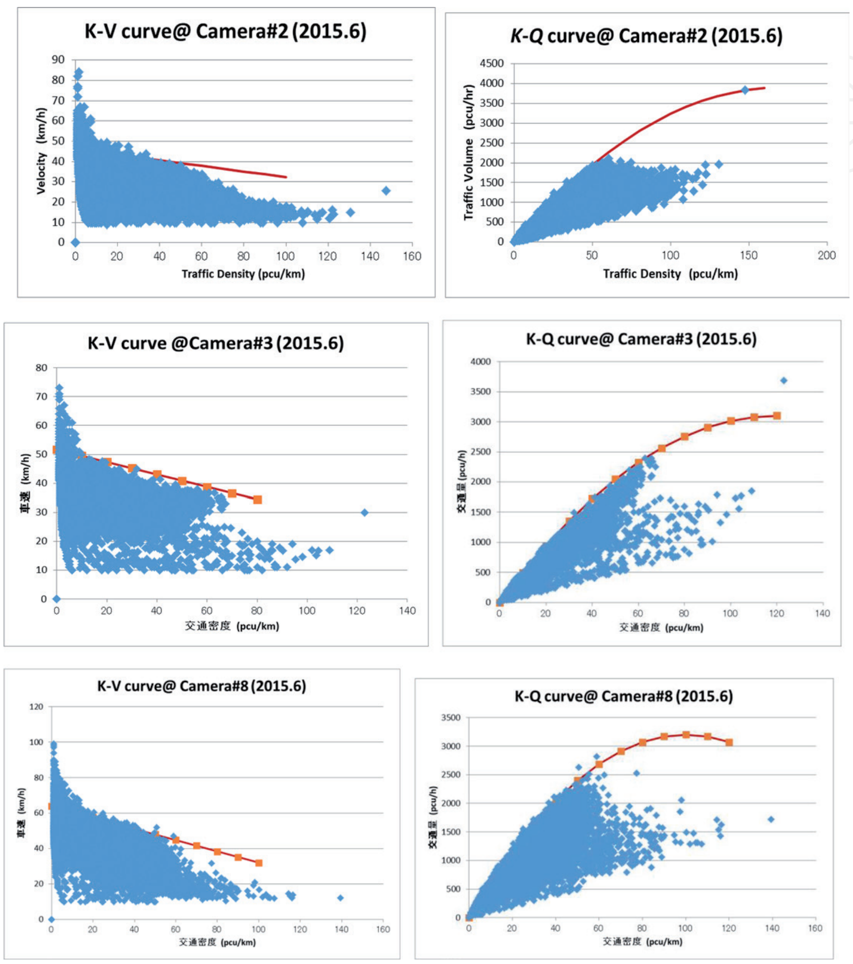

Figure 17.
Traffic flow characteristics in Ahmedabad June 2015.

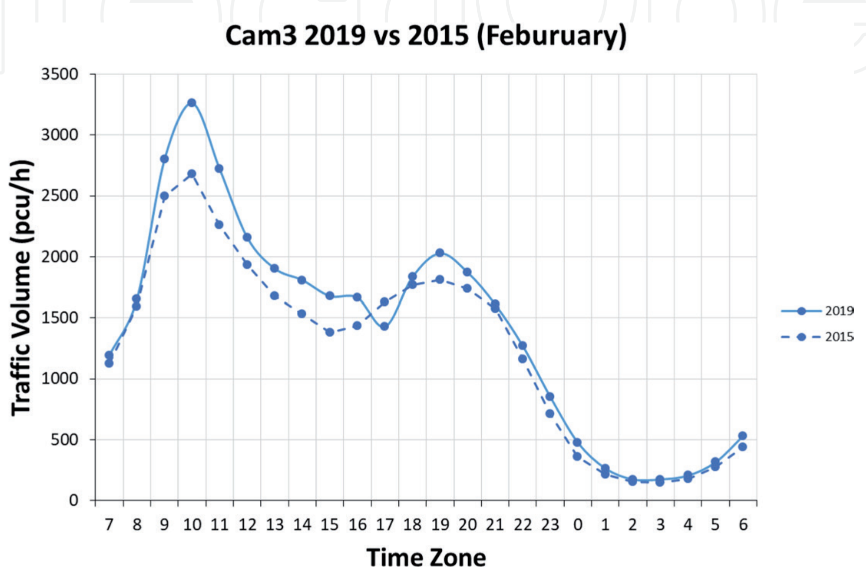

Figure 18.
Comparison time-based traffic volume between 2015 and 2019.

5. Conclusion

In terms of the book title "Megacities – Intelligence, Sustainable and Resilience Built Environment", we see transportation case study in a major mega city Ahmedabad city in Gujarat state of India. And we know traffic issues are critical not only in India but also in any country in the world. The each country difference is based on each countries" condition, economics, social condition, relationship with other cities, states, and countries.

In this chapter, we focus on transportation and pick up one of typical city case study in India. From this case study, the visualization of traffic condition is key especially for understanding real traffic condition in India and it is useful to use advanced engineering technology for sensing traffic condition. We find several reason why the traffic congestion occurs in Ahmedabad city in the case study. From this research, the traffic congestion does not always occur and there is some other reason behind such as unbalance between number of vehicle growth and lack of infrastructure development. This situation is not exception in other advanced countries.

The most important research is to focus on the real human activities, especially transport field. And it is also important to learn other experience of other countries. We see some example for traffic fatality analysis based on Japanese experience. Therefore this kind of research should be shared among the related stakeholders and listen their voice. In some case, it is important that we should understand the target megacities requirement and situation and how to use each experience and share with them. This is not only providing advanced, tools, facilities but our experience in which we have also had similar condition in the past. It enable to us for creating new idea and solution during studies towards our unexpected matters in future.

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